Supplementary Material

Trimming defective perovskite layer surface for high-performance solar cells

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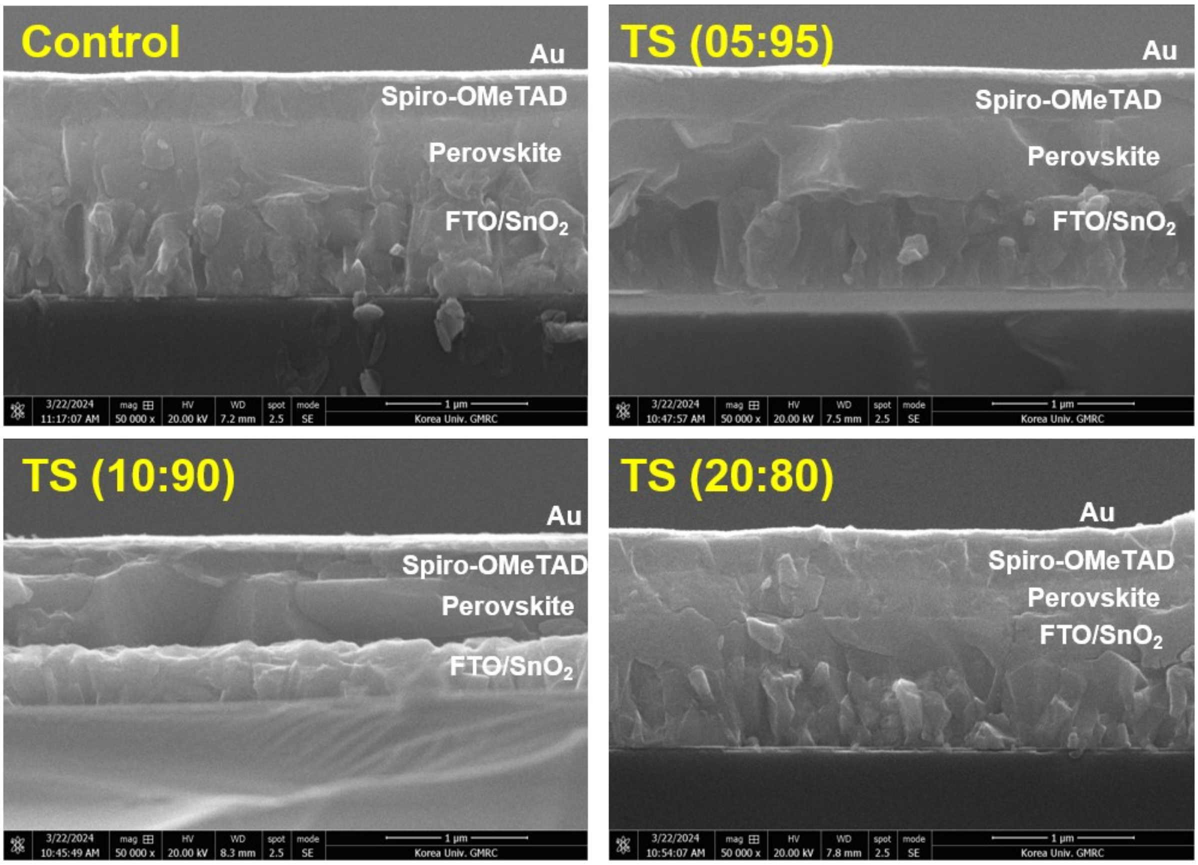


Fig. S1. Cross-sectional SEM images of the control, TS (05:95), TS (10:90), and TS (20:80) devices.

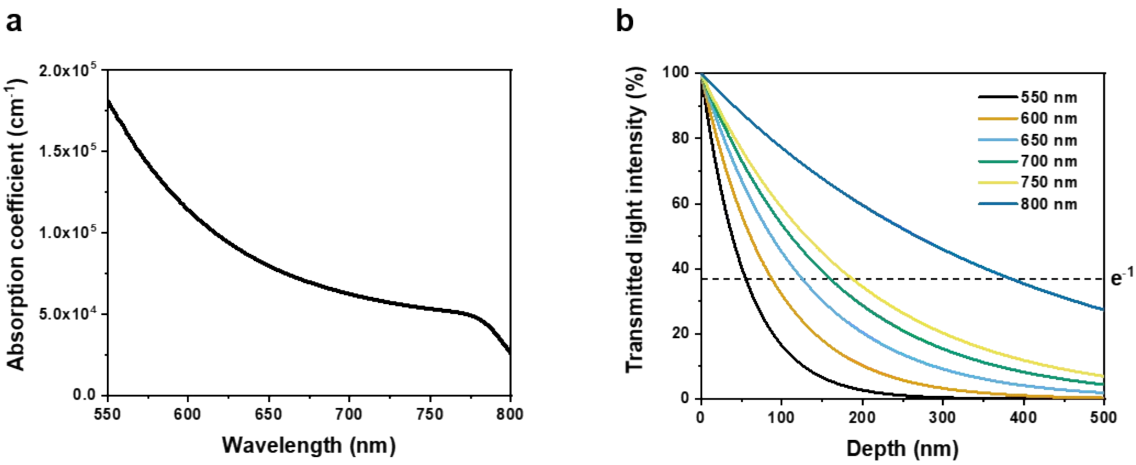


Fig. S2. **(a)** Absorption coefficient of the perovskite layer and **(b)** transmitted light intensity for different wavelengths.

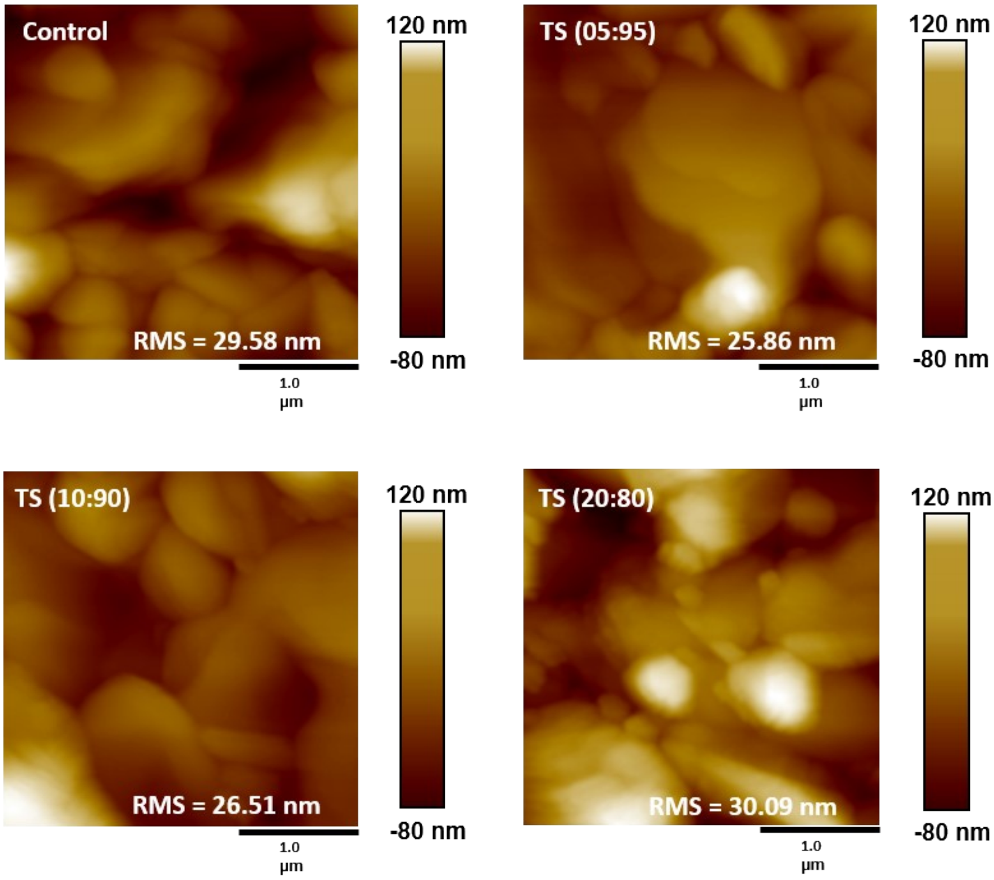


Fig. S3. Atomic force microscopy images of the control, TS (05:95), TS (10:90), and TS (20:80) perovskite thin films.

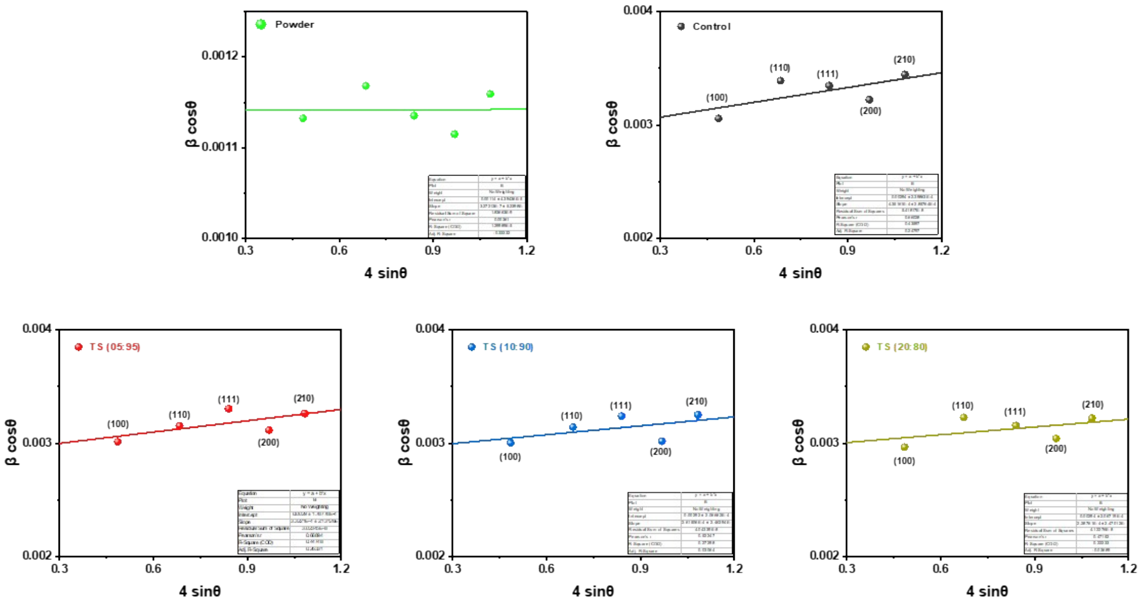


Fig. S4. Williamson-Hall plots of the control, TS (05:95), TS (10:90), and TS (20:80) perovskite thin films.

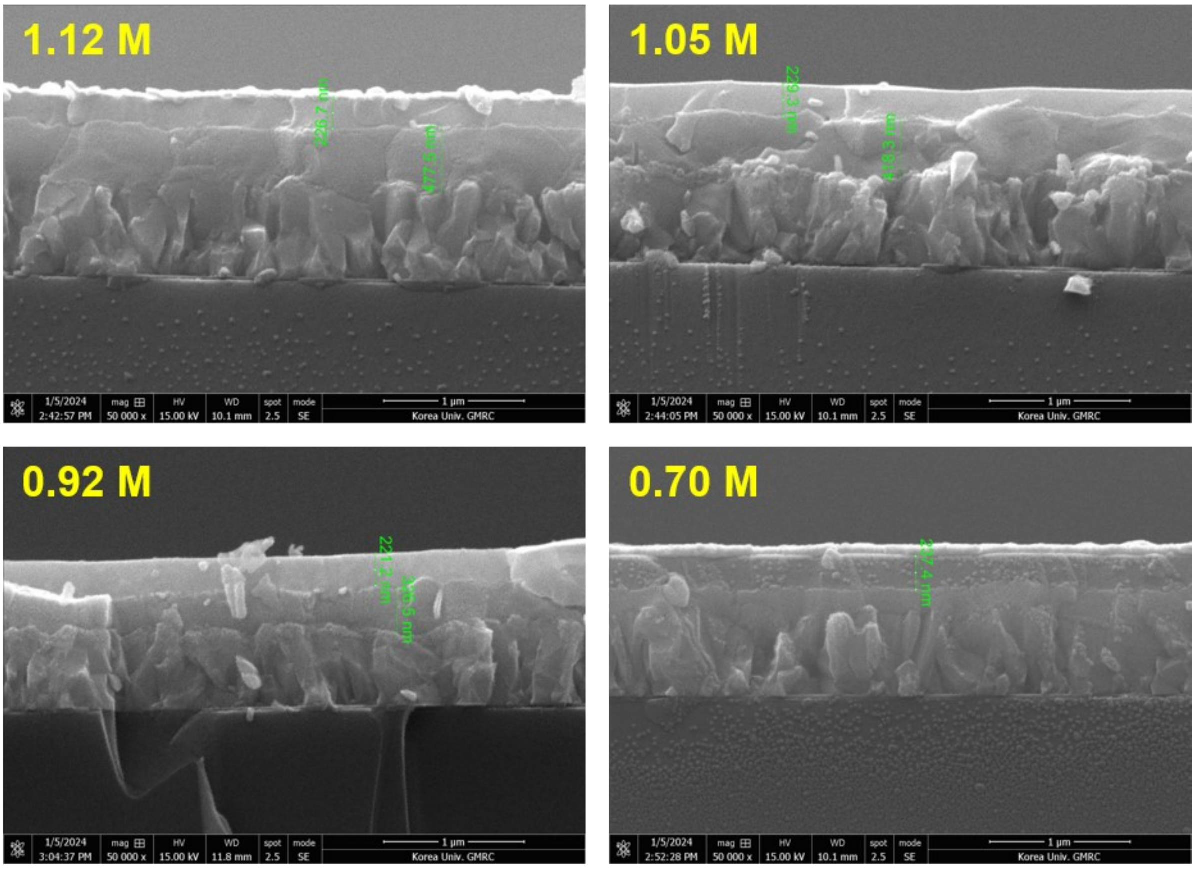


Fig. S5. Cross-sectional SEM images of the perovskite film for different perovskite precursor concentrations.

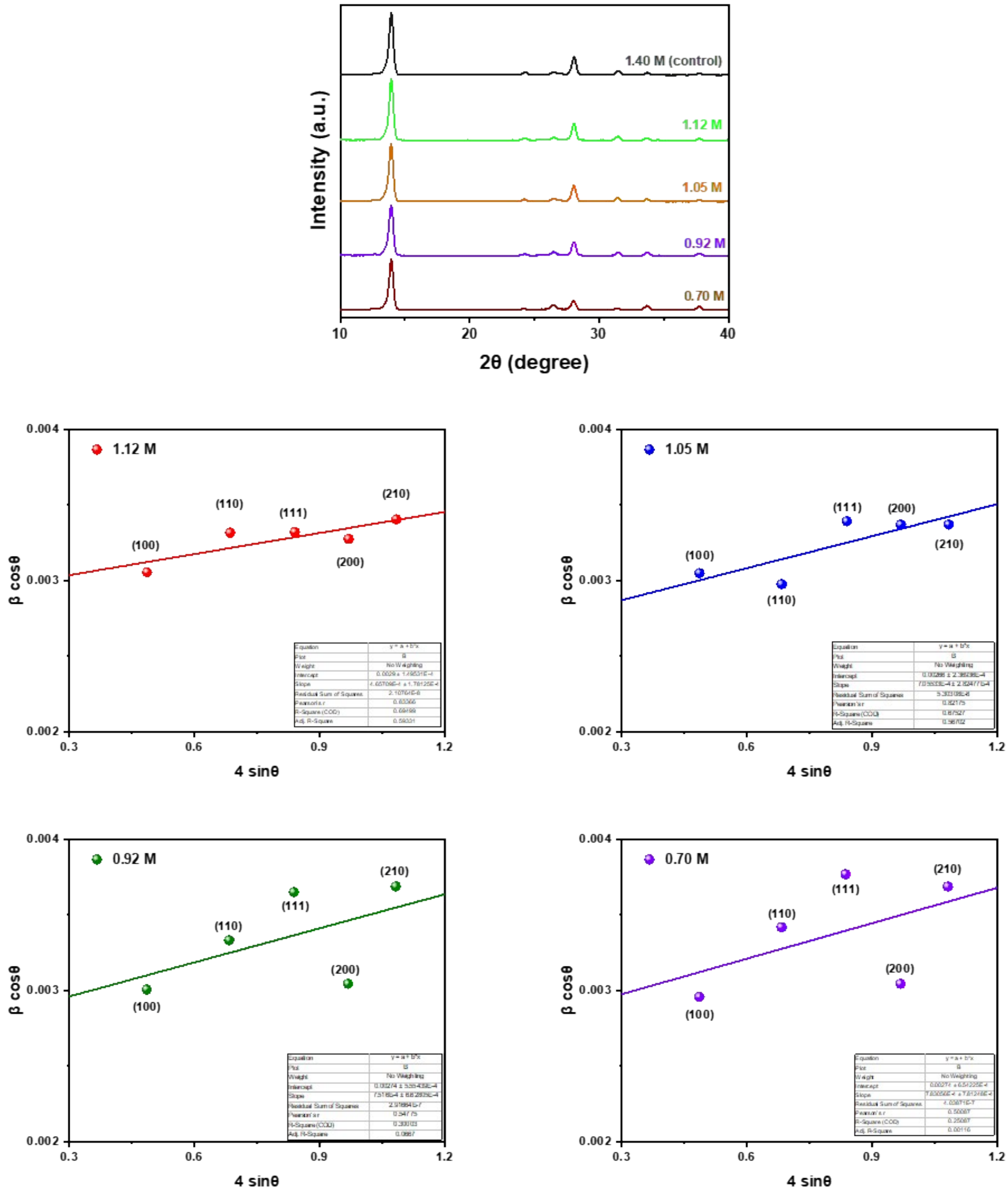


Fig. S6. XRD patterns and individual Williamson-Hall plot of the perovskite thin films prepared with 1.40 M, 1.12 M, 1.05 M, 0.92 M, and 0.70 M of $FAPbI_3$.

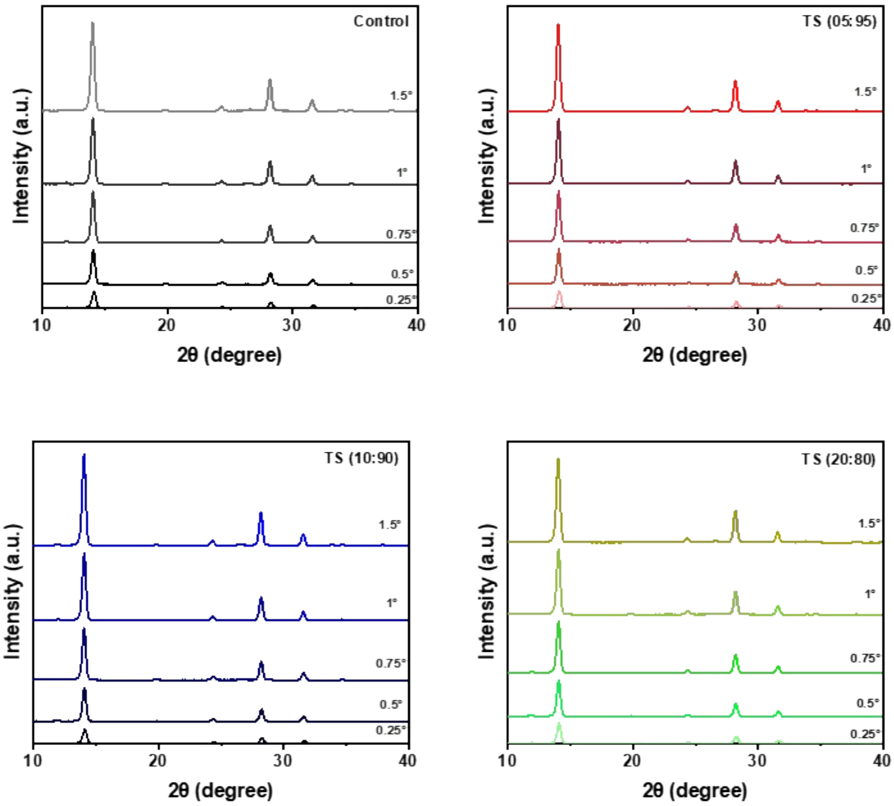


Fig. S7. GIXRD patterns of the control, TS (05:95), TS (10:90), and TS (20:80) perovskite thin films at different incidence angles.

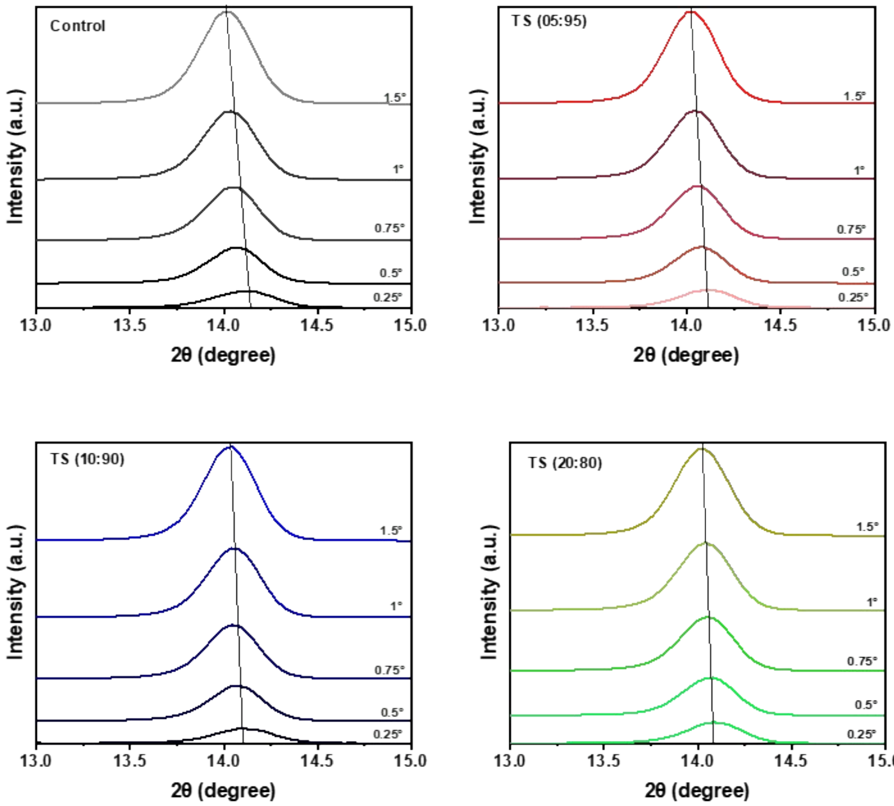
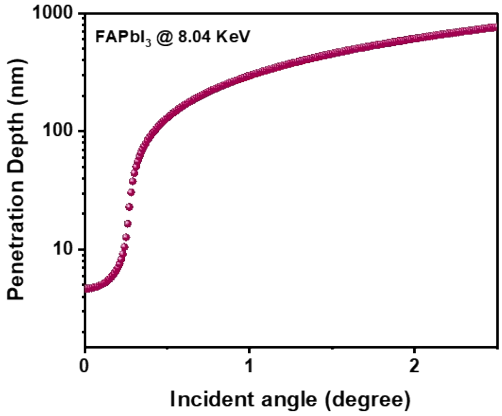


Fig. S8. Magnified GIXRD peaks corresponding to the (100) plane of the control, TS (05:95), TS (10:90), and TS (20:80) perovskite films at varying incidence angles.



Grazing incident angle (degree)	Penetration depth (nm)
0.25	12.7
0.5	123.8
0.75	217.1
1	298.2
1.5	456.47
2	612.8

Fig. S9. X-ray penetration depth Λ into the $FAPbI_3$ layer at different incidence angles, calculated as:

$$\Lambda = \frac{\lambda}{\sqrt{2}\pi} \times \frac{1}{\sqrt{\sqrt{(\alpha_i^2 - \alpha_c^2)^2 + 4\beta^2} - (\alpha_i^2 - \alpha_c^2)}}$$

**Density of $FAPbI_3$, d= 4.101g/cm3, From Inorg. Chem. 2013, 52, 9019-9038*

where α_i is the incidence angle, α_c is the critical angle of the sample, λ is the X-ray wavelength, and β is the imaginary part of the refraction index, defined as n = 1 - δ + iβ. The δ and β parameters for $FAPbI_3$ at 8.04 keV (λ = 1.54 Å) were 1.08329×10^{-5} and 1.22906×10^{-6}, respectively, as determined using the online toolbox available at *https://henke.lbl.gov/optical_constants/getdb2.html.*

Table S1. Microstrains calculated from the GIXRD patterns of the control, TS (05:95), TS (10:90), and TS (20:80) thin films at different incidence angles.

Incidence angle	0.25° (ε x 10^4)	0.5° (ε x 10^4)	0.75° (ε x 10^4)	1° (ε x 10^4)	1.5° (ε x 10^4)
Control	4.3223	3.8565	1.9579	0.3856	0.2551
TS (05:95)	3.9907	2.9453	1.7198	0.3545	0.2537
TS (10:90)	3.2813	2.8302	1.4861	0.3249	0.2586
TS (20:80)	2.7364	2.1199	1.2695	0.3105	0.2547

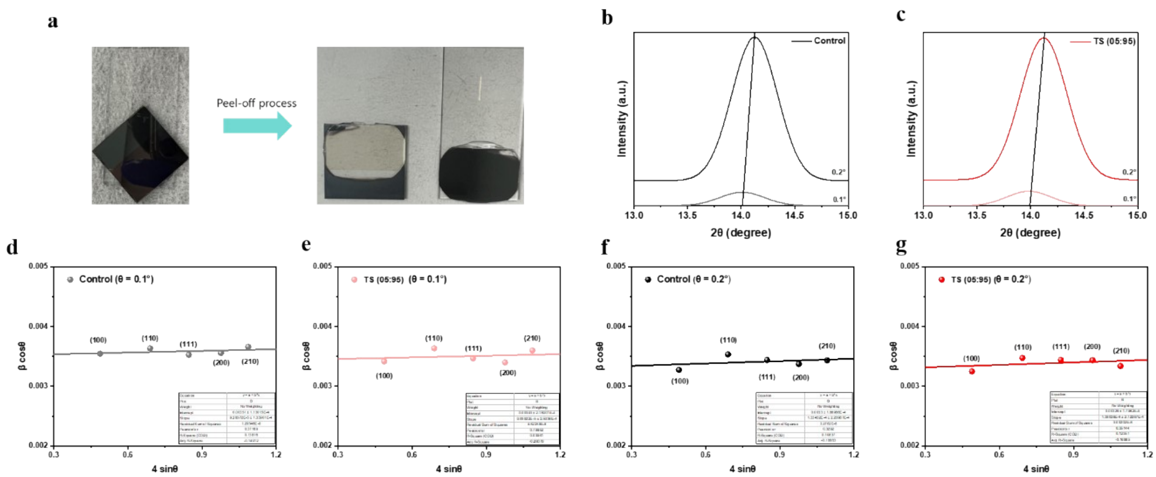


Fig. S10. (a) Perovskite film peeled-off from the substrate. **(b-c)** Magnified GIXRD diffraction peaks corresponding to the (100) plane of the buried interface. **(d-g)** WH plots of the buried interface of the control and TS (05:95).

Table S2. Microstrains calculated from the GIXRD patterns of the buried interface of the control and TS (05:95) thin films at different incidence angles.

Incidence angle	0.1° (ε x 10^4)	0.2° (ε x 10^4)
Control	0.9285	1.3343
TS (05:95)	0.9099	1.3802

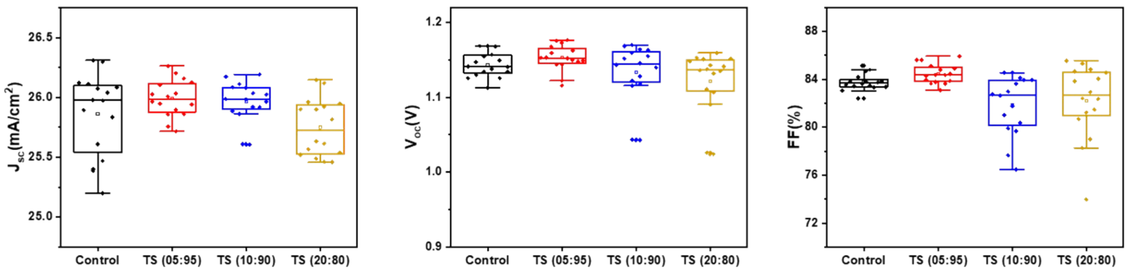
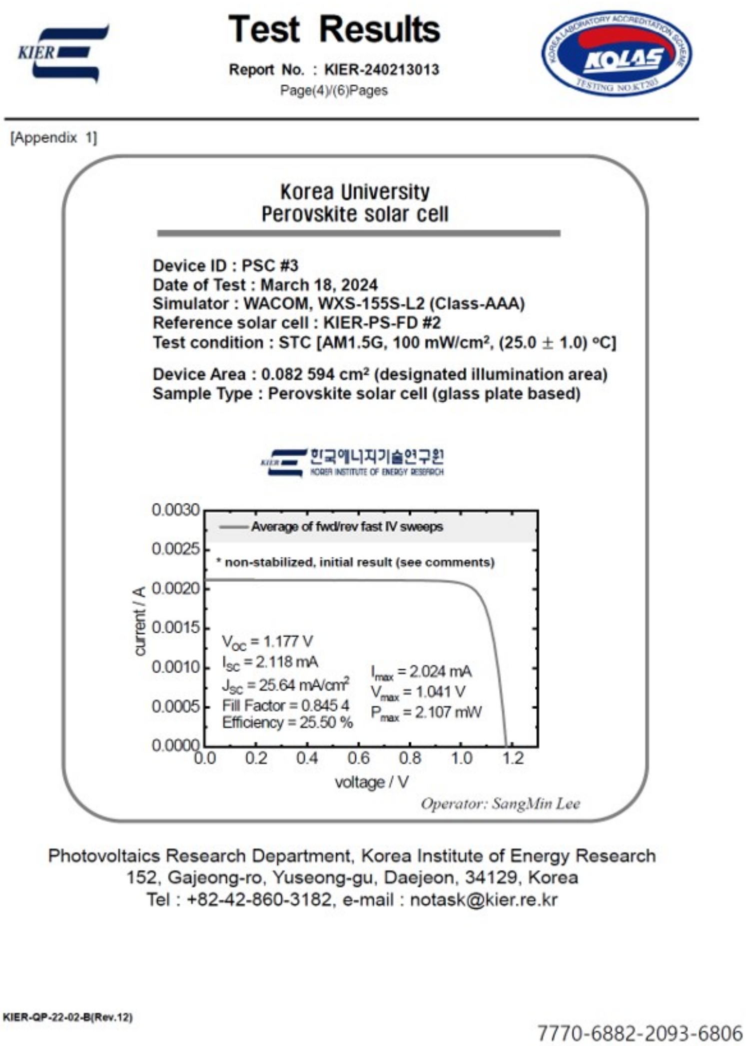


Fig. S11. Statistics of key performance parameters of the control, TS (05:95), TS (10:90), and TS (20:80) devices.



Test Results

Report No. : KIER-240213013

Page(4)/(6)Pages

[Appendix 1]

Korea University
Perovskite solar cell

Device ID : PSC #3
Date of Test : March 18, 2024
Simulator : WACOM, WXS-155S-L2 (Class-AAA)
Reference solar cell : KIER-PS-FD #2
Test condition : STC [AM1.5G, 100 mW/cm², (25.0 ± 1.0) °C]

Device Area : 0.082 594 cm² (designated illumination area)
Sample Type : Perovskite solar cell (glass plate based)

Operator: SangMin Lee

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Tel : +82-42-860-3182, e-mail : notask@kier.re.kr

KIER-QP-22-02-B(Rev.12)

7770-6882-2093-6806

Fig. S12. Independent PCE certification issued by the Korea Institute of Energy Research.

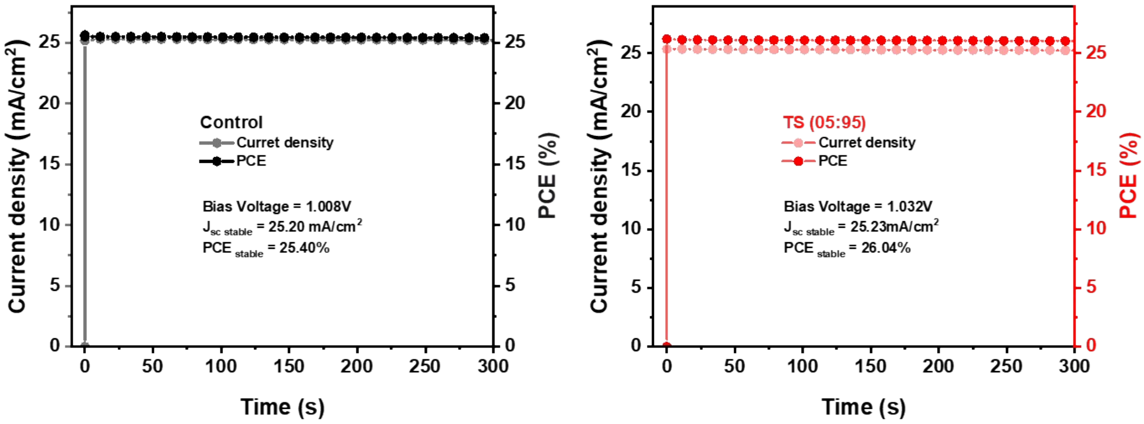

Fig. S13. Stabilized power output and current density at the maximum power point for the control and TS (05:95) devices.

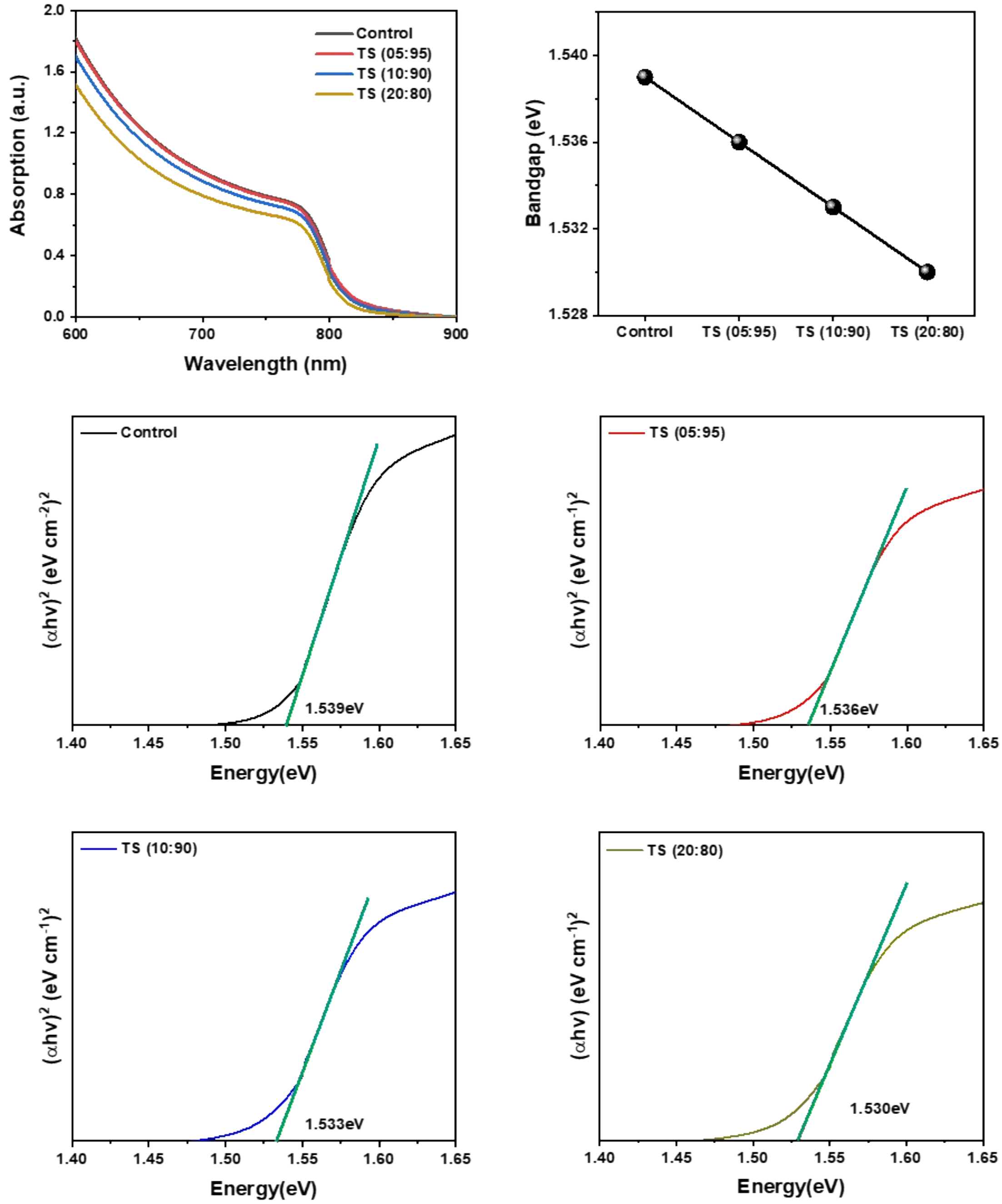

Fig. S14. UV-vis absorption spectra and bandgaps of the control, TS (05:95), TS (10:90), and TS (20:80) perovskite thin films.

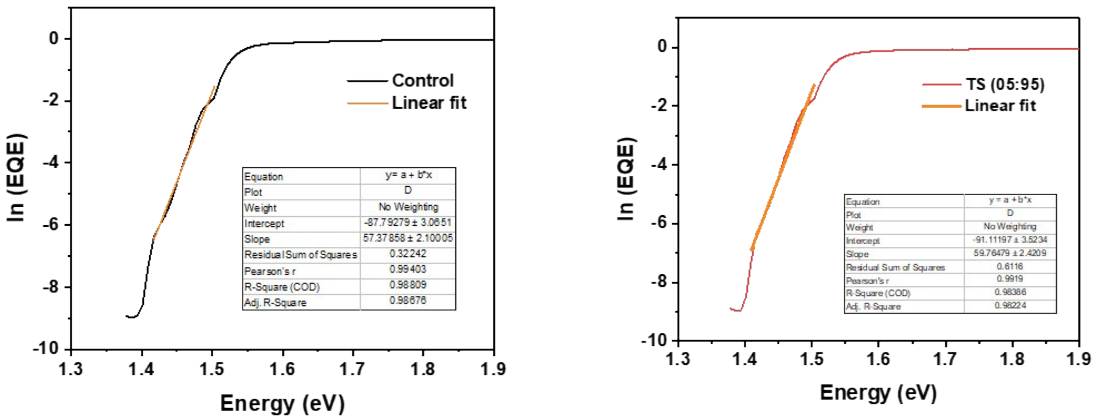

Fig. S15. Semilog EQE vs photon energy for the control and TS (05:95) devices.